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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
(Docket No. 15-XT-4847)

PATENT APPLICATION OF:)
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Richard Michael Roffers)
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SERIAL NO.:)
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FILED: Herewith)
)
FOR: METHOD AND APPARATUS FOR)
REDUCING HIGH VOLTAGE BREAKDOWN)
EVENTS IN X-RAY TUBES)
)

EXPRESS MAIL NO. EL 541892080US
Date: September 20, 2000

Assistant Commissioner for Patents
BOX PATENT APPLICATION
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of Inventor(s): Richard Michael Roffers

For: **METHOD AND APPARATUS FOR REDUCING HIGH VOLTAGE BREAKDOWN
EVENTS IN X-RAY TUBES**

1. Enclosed are:
- ☒ [X] Declarations and Powers of Attorney signed by the inventor.
 - ☒ [X] 2 Sheet(s) of drawing(s) (informal).
 - ☒ [X] 9 pages of specification including a 1 page abstract, and 3 page(s) of claims (Claims 1-20).
 - ☐ [] A verified statement to establish small entity status under 37 C.F.R. 1.9 and 37 C.F.R. 1.27.
 - ☒ [X] Assignment and Recordation Form Cover Sheet. Also included is the \$40.00 assignment fee.
 - ☐ [] An associate power of attorney.
 - ☐ [] A Transmittal of Information Disclosure Statement and its enclosures.

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☐ Priority Document

2. Benefit of the filing date of each priority document or U.S. provisional patent application listed below (if any) is claimed under 35 U.S.C. Section 119 and Section 120:

<u>Docket No.</u>	<u>Country</u>	<u>Appl'n. Serial No.</u>	<u>Filing Date</u>
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3. The filing fee has been calculated as shown below, based on the assignee's status as a large entity:

	Claims Presented	Extra Claims	Rate per Extra claim	
Total Claims	- 20	0	X \$ 18 .00	
Indep Claims	- 3	0	X \$ 78.00	
Basic fee				\$690.00
Multiple dependent claim presented (\$260 if any present)				<u>\$.00</u>
Total Filing fee				<u>\$690.00</u>

4. The following arrangements have been made to pay the filing fee:

- ☒ A check in the amount of \$690.00 to cover the filing fee is enclosed.
- ☐ The filing fee is not enclosed. This form does not authorize a charge to a deposit account.
- ☐ Please charge our Deposit Account No. 13-0017 in the amount of \$~.
- ☒ The Commissioner is hereby authorized to charge any additional filing fees which may be required under 37 C.F.R. 1.16 for this application and for any amendment thereto, or credit any overpayment to Account No. 13-0017.

5. The Commissioner is hereby authorized to charge payment of the following fees during the pendency of this application or credit any overpayment to Deposit Account No. 13-0017.

- ☐ No charges are authorized.
- ☒ Any patent application processing fees under 37 C.F.R. 1.17.

6. Please address all telephone calls to: John F. Nethery

at telephone No. (312) 707-8889.

McAndrews, Held & Malloy, Ltd.
34th Floor
500 West Madison Street
Chicago, Illinois 60661

Date: September 20, 2000

Joseph M. Barich
Reg. No. 42,291

Method and Apparatus for Reducing High Voltage
Breakdown Events in X-ray Tubes

BACKGROUND OF THE INVENTION

The present invention relates to X-ray tubes. In particular, the present invention relates to a method and apparatus for reducing high voltage breakdown events in X-ray tubes.

X-ray imaging systems have long been available to doctors as a valuable tool for examination and diagnosis. X-ray imaging systems rely on an evacuated high voltage (e.g., 30-150kV) X-ray tube. The X-ray tube produces an X-ray beam by generating an electron beam at the tube cathode, focusing the electron beam through a focus grid, and impacting the electron beam upon a tube anode. A steady, predictable X-ray beam greatly enhances the diagnostic usefulness of an X-ray system. However, past X-ray tubes suffered from a deleterious effect called high voltage breakdown or vacuum arcing that interrupted the steady X-ray beam.

The prevailing theory on electrical breakdown of the vacuum gap in the X-ray tube is predicated on the intensification of the electric field near the cathode surface caused by positive ion space charge formation in the region above the cathode surface. The electric field intensification results in an increase in localized currents from field emission sites on much of the cathode surface as well as neutralization of negative thermionic space charge about the filament that serves to reduce the electrostatic shielding of emitters found in that region. When the current density from an emitter is high enough to cause substantial Joule heating of the emitter tip, the constituent emitter material can sublime into the vacuum gap where it can be ionized. Ensuing plasma formation and high voltage breakdown results in the vacuum gap across the gap between the cathode to anode.

High voltage breakdown events short circuit the X-ray tube and interrupt the X-ray beam. In order to mitigate the interruptions, X-ray tubes undergo an extensive burn-in procedure after manufacture. The burn-in procedure attempts to eliminate, through electrical discharge, cathode field emission sites by allowing high voltage breakdowns to occur in a controlled fashion. While the burn-in procedure helps to reduce high voltage breakdowns in installed X-ray systems to a certain extent, the burn-in procedure does not completely eliminate all field emission sites. As a

result, installed X-ray systems continue to experience high voltage breakdowns and the resultant interruptions in the X-ray beam.

A need has long existed in the industry for a method and apparatus for reducing high voltage breakdown events in X-ray tubes that addresses the problems noted above, and others previously experienced.

BRIEF SUMMARY OF THE INVENTION

A preferred embodiment of the present invention provides an X-ray tube subsystem including an X-ray tube and a grid voltage supply. The X-ray tube provides a grid bias connection, a filament bias connection, and an anode bias connection. The grid voltage supply is connected to the grid bias connection and filament bias connection, and is adapted to produce an ion collection voltage substantially less than an electron beam focus voltage, to sweep free ions out of the X-ray tube.

Another preferred embodiment of the present invention provides a method for operating an X-ray system to reduce high voltage breakdown events. The method includes the steps of providing an X-ray tube that includes a grid bias connection and filament bias connection. In addition, during X-ray tube operation, the method creates an ion collection voltage between the grid bias connection and the filament bias connection that is substantially less than an electron beam focus voltage, to sweep free ions out of the X-ray tube.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an X-ray examination system including an X-ray tube subsystem.

Figure 2 illustrates a method of operating an X-ray tube examination system.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to Figure 1, that figure shows an X-ray examination system 100 including an X-ray tube subsystem 102, an X-ray detector 104 positioned to receive the X-ray beam 106, and readout electronics 108 connected to the X-ray detector 104 (e.g., film, or a solid state X-ray detector).

5 The X-ray tube subsystem 102 includes an X-ray tube 110 and supporting filament voltage supply 112, anode voltage supply 114, and cathode voltage supply 116. Internal to the X-ray tube is a filament 118, a focus grid 120 (sometimes referred to as a grid, or cup), and a rotating anode 122. A focus grid voltage supply 124 (which may be a fixed or variable voltage supply) is connected
10 between the focus grid and the filament. An optional Faraday cage 126 surrounds the focus grid voltage supply 124. Figure 1 also generally indicates external connections to the X-ray tube including the filament bias connection 127, anode bias connection 128, and the grid bias connection 130, to which the voltage supplies 112-116 connect. A reference earth ground is indicated at 132.

15 During operation of the X-ray tube 110, the filament voltage supply 112 produces a filament voltage on the order of 10 to 40 volts at approximately 4 to 10 amps in order to heat the filament to the extent required to produce free electrons. The anode voltage supply 114 and the cathode voltage supply 116 provide a working
20 voltage across the X-ray tube of approximately 30-150kV in order to accelerate the electrons into an electron beam that impacts the rotating anode 122 at very high velocity. The result is the X-ray beam 106. In one embodiment, the anode voltage supply produces a voltage in the range 15kV to 75 kV, and the cathode voltage supply produces a voltage in the range -15kV to -75kV referenced to the earth ground 132.

25 The grid voltage supply 124 produces a positive ion collection voltage on the order of 10 to 30 volts at several milliamps. The ion collection voltage sweeps free positive ions out of the X-ray tube 110 and, as explained in more detail below, reduces high voltage breakdown events in the X-ray tube 110. Note that the focus grid 120 may also be used to focus the electron beam or to stop the electron beam
30 from reaching the anode 122. However, the voltage typically required to focus the electron beam is on the order of 100 to 300 volts, while the voltage typically required to stop the electron beam is on the order of several kilovolts. Thus, the relatively small ion collection voltage neither interferes with electron beam focusing, nor propagation of the electron beam to the anode.

5 The Faraday cage 126 is connected to the filament bias connection. As a result, the Faraday cage 126 provides an electromagnetic shield for the components operating inside the focus grid supply 124. The Faraday cage 126 is preferably provided when electromagnetically sensitive components are used to generate the ion collection voltage.

10 The normal operation of the X-ray tube 110 results in positive ion space charge formation around the cathode (i.e., the filament 118 and focus grid 120) as a result, for example, of collisions of electrons with residual gas molecules in the X-ray tube 110. The ion collection voltage sweeps away the positive ions and eliminates their effect on the electric field around the cathode. The absence of the positive ion space charge above the cathode surface results in a relative uniform electric field, or potential gradient, between the anode and cathode and lowers the probability of high voltage breakdowns.

15 On the other hand, when present, the positive ion space charge intensifies the electric field between the cathode and the region of space including the positive ion space charge. The probability of the high voltage breakdown increases dramatically because intensified electric field generates addition current and therefore additional heat in the field emitters on the cathode. The heating eventually causes sublimation of cathode material into the X-ray tube 110. A high voltage breakdown or vacuum arc results, and the X-ray beam 106 is undesirably shut off until the high voltage breakdown subsides.

20 Secondly, during normal operation of the X-ray tube 100, a negative space charge exists near the filament due to electrons leaving the filament to form the electron beam. The negative space charge has a shielding effect on the field emitters on the filament surface. However, the positive ions interact with and neutralize electrons around the filament. The shielding effect is reduced, the local electric field is increased, and the field emitters are more susceptible to the heating mechanism explained above that causes high voltage breakdowns.

30 However, the ion collection voltage applied between the focus grid 120 and the filament 118 draws away the positive ions above the cathode surface. The two breakdown mechanisms identified above are therefore far less likely to occur. The result is that high voltage breakdowns are less frequent.

Turning next to Figure 2, that figure illustrates a flow diagram 200 of the steps that occur before and during operation of the X-ray examination system 100. At step 202, an X-ray tube with grid and filament bias connections is provided. At step 204, a Faraday cage is provided around the focus grid voltage supply. Next, at
5 step 206, the ion collection voltage that the focus grid supply will generate is selected. As noted above, the ion collection voltage is generally between 10 to 30 volts, and may be selected by operating and observing the X-ray tube 110 to determine which ion collection voltage results in the greatest reduction in high voltage breakdowns. During operation of the tube, the ion collection voltage is generated between the focus
10 grid 120 and filament 118 to sweep positive ions out of the X-ray tube 110.

The net effect of the small negative ion collection voltage is a reduction in the probability of high voltage breakdown events in the X-ray tube 110. As a result, there are fewer interruptions in the X-ray beam 106. The X-ray system 100 thus operates in a more reliable, consistent, and diagnostically useful manner.

15 While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular step, structure, or material to the teachings of the invention without departing from its
20 scope. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. An X-ray tube subsystem comprising:

an X-ray tube including a grid bias connection, a filament bias connection, and an anode bias connection; and

a grid voltage supply connected to the grid bias connection, the grid voltage supply adapted to produce an ion collection voltage substantially less than an electron beam focus voltage.

2. The X-ray tube subsystem of claim 1, wherein the ion collection voltage is in the range of 10 to 30 volts.

3. The X-ray tube subsystem of claim 1, wherein the electron beam focus voltage is greater than 100 volts, and the ion collection voltage is in the range 10 to 30 volts.

4. The X-ray tube subsystem of claim 1, further comprising a Faraday cage surrounding the grid voltage supply.

5. The X-ray tube subsystem of claim 1, wherein the grid voltage supply is a variable grid voltage supply.

6. The X-ray tube subsystem of claim 1, further comprising a filament voltage supply connected to the filament bias connection.

7. The X-ray tube subsystem of claim 6, wherein the Faraday cage is connected to the filament voltage supply.

8. The X-ray tube subsystem of claim 6, further comprising an anode voltage supply connect to the anode bias connection and a ground reference, and a cathode voltage supply connected to the earth ground and the filament bias connection.

9. A method for operating an X-ray system to reduce high voltage breakdown events, the method comprising:

providing an X-ray tube that includes a grid bias connection and filament bias connection;

during X-ray tube operation, creating an ion collection voltage between the grid bias connection and the filament bias connection that is substantially less than an electron beam focus voltage, to sweep free ions out of the X-ray tube.

10. The method of claim 9, wherein the step of creating an ion collection voltage comprises creating an ion collection voltage in the range of 10 to 30 volts.

11. The method of claim 9, further comprising the step of calibrating the X-ray tube before examination to determine the ion collection voltage.

12. The method of claim 9, further comprising the step of providing a Faraday cage surrounding a grid voltage supply that creates the ion collection voltage.

13. The method of claim 12, further comprising providing a connection between the Faraday cage and the filament bias connection.

14. An X-ray examination system comprising:

an X-ray tube including a grid bias connection and a filament bias connection;

a grid voltage supply connected to the grid bias connection, the grid voltage supply adapted to produce an ion collection voltage substantially less than an electron beam focus voltage to sweep free ions out of the X-ray tube;

an X-ray detector positioned to receive the electron beam; and

readout electronics connected to the X-ray detector.

15. The X-ray examination system of claim 14, wherein the ion collection voltage is in the range of 10 to 30 volts.

16. The X-ray examination system of claim 14, further comprising a Faraday cage surrounding the grid voltage supply.

17. The X-ray examination system of claim 16, wherein the Faraday cage is connected to the filament bias connection.

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20. The X-ray examination system of claim 14, wherein the X-ray tube operates under a tube voltage substantially in the range 100-150kV, the electron beam focus voltage is greater than 100 volts, and the ion collection voltage is substantially in the range of 10 to 30 volts.

G.E. DOCKET NUMBER

Method and Apparatus for Reducing High Voltage
Breakdown Events in X-ray Tubes

ABSTRACT OF THE DISCLOSURE

An X-ray tube subsystem including an X-ray tube and a grid voltage supply that reduces high voltage breakdown events. The X-ray tube provides a grid bias connection, a filament bias connection, and an anode bias connection. The grid voltage supply is connected to the grid bias connection and is adapted to produce an ion collection voltage substantially less than an electron beam focus voltage.

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Figure 1

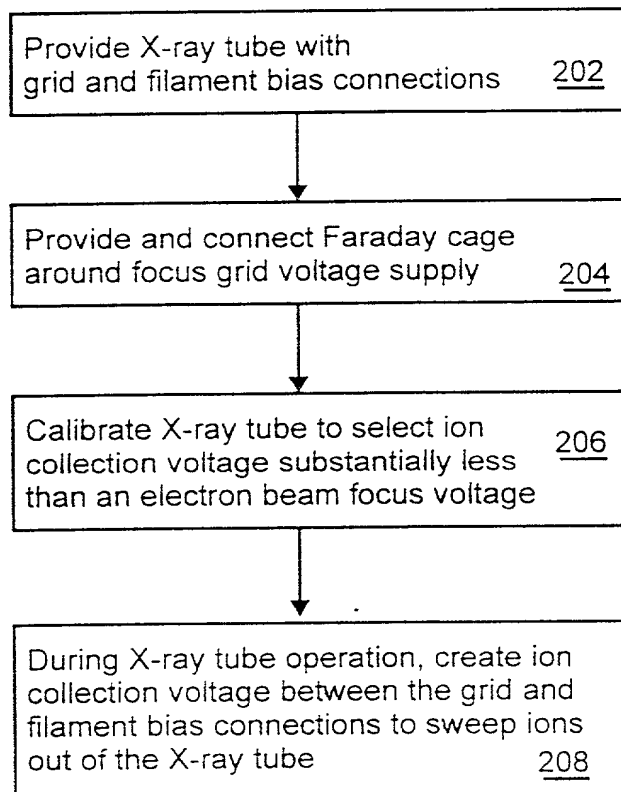
[illegible]

Figure 2

**COMBINED DECLARATION AND
POWER OF ATTORNEY FOR PATENT APPLICATION**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**METHOD AND APPARATUS FOR REDUCING HIGH
VOLTAGE BREAKDOWN EVENTS IN X-RAY TUBES**

the specification of which:

☒ X is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information which I know to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below. I have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

<u>Number</u>	<u>Country</u>	<u>Day/Month/Year Filed</u>	<u>Is Priority Claimed?</u>
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None

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

<u>Application Number</u>	<u>Filing Date</u>
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None

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below. Insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

Serial No. Filing Date Patented, Pending, or Abandoned?

None

I hereby appoint the following attorneys and/or agents to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Christian G. Cabou	Reg. No. 35,467
Phyllis Y. Price	Reg. No. 34,234
Michael A. Della Penna	Reg. No. 45,697
Ronald E. Myrick	Reg. No. 26,315
Henry J. Policinski	Reg. No. 26,621
Jay L. Chaskin	Reg. No. 24,030
George P. McAndrews	Reg. No. 22,760
John J. Held	Reg. No. 21,061
Timothy J. Malloy	Reg. No. 25,600
William M. Wesley	Reg. No. 26,521
Lawrence M. Jarvis	Reg. No. 27,341
Gregory J. Vogler	Reg. No. 31,313
Jean Dudek Kuelper	Reg. No. 30,171
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Robert W. Fieseler	Reg. No. 31,826
D. David Hill	Reg. No. 35,543
Thomas J. Wimbiscus	Reg. No. 36,059
Steven J. Hampton	Reg. No. 33,707
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Janet M. McNicholas	Reg. No. 32,918
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Donald J. Pochopien	Reg. No. 32,167
Sharon A. Hwang	Reg. No. 39,717

David D. Headrick	Reg. No. 40,642
Dean D. Small	Reg. No. 34,730
Alejandro Menchaca	Reg. No. 34,389
Kirk A. Vander Leest	Reg. No. 34,036
Richard T. McCaulley, Jr.	Reg. No. 41,977
Anthony E. Dowell	Reg. No. 39,661
Peter J. McAndrews	Reg. No. 38,547
Michael B. Harlin	Reg. No. 43,658
Jonathan R. Sick	Reg. No. 43,920
Eligio C. Pimentel	Reg. No. 42,076
John F. Nethery	Reg. No. 42,928
James Nuttall	Reg. No. 44,978
James P. Murphy	Reg. No. 40,741
Dean A. Pelletier	Reg. No. 45,007
Joseph M. Barich	Reg. No. 42,291
Scott P. McBride	Reg. No. 42,853
Patricia J. McGrath	Reg. No. 44,919

Address all telephone calls to John F. Nethery at telephone number:

(312) 707-8889.

Address all correspondence to:

John F. Nethery
McAndrews, Held & Malloy, Ltd.
34th Floor
500 W. Madison Street
Chicago, Illinois 60661

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

This declaration names 1 inventor(s) below.

1997-1998		1998-1999		1999-2000		2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022		2022-2023		2023-2024		2024-2025		2025-2026		2026-2027		2027-2028		2028-2029		2029-2030		2030-2031		2031-2032		2032-2033		2033-2034		2034-2035		2035-2036		2036-2037		2037-2038		2038-2039		2039-2040		2040-2041		2041-2042		2042-2043		2043-2044		2044-2045		2045-2046		2046-2047		2047-2048		2048-2049		2049-2050		2050-2051		2051-2052		2052-2053		2053-2054		2054-2055		2055-2056		2056-2057		2057-2058		2058-2059		2059-2060		2060-2061		2061-2062		2062-2063		2063-2064		2064-2065		2065-2066		2066-2067		2067-2068		2068-2069		2069-2070		2070-2071		2071-2072		2072-2073		2073-2074		2074-2075		2075-2076		2076-2077		2077-2078		2078-2079		2079-2080		2080-2081		2081-2082		2082-2083		2083-2084		2084-2085		2085-2086		2086-2087		2087-2088		2088-2089		2089-2090		2090-2091		2091-2092		2092-2093		2093-2094		2094-2095		2095-2096		2096-2097		2097-2098		2098-2099		2099-2100		2100-2101		2101-2102		2102-2103		2103-2104		2104-2105		2105-2106		2106-2107		2107-2108		2108-2109		2109-2110		2110-2111		2111-2112		2112-2113		2113-2114		2114-2115		2115-2116		2116-2117		2117-2118		2118-2119		2119-2120		2120-2121		2121-2122		2122-2123		2123-2124		2124-2125		2125-2126		2126-2127		2127-2128		2128-2129		2129-2130		2130-2131		2131-2132		2132-2133		2133-2134		2134-2135		2135-2136		2136-2137		2137-2138		2138-2139		2139-2140		2140-2141		2141-2142		2142-2143		2143-2144		2144-2145		2145-2146		2146-2147		2147-2148		2148-2149		2149-2150		2150-2151		2151-2152		2152-2153		2153-2154		2154-2155		2155-2156		2156-2157		2157-2158		2158-2159		2159-2160		2160-2161		2161-2162		2162-2163		2163-2164		2164-2165		2165-2166		2166-2167		2167-2168		2168-2169		2169-2170		2170-2171		2171-2172		2172-2173		2173-2174		2174-2175		2175-2176		2176-2177		2177-2178		2178-2179		2179-2180		2180-2181		2181-2182		2182-2183		2183-2184		2184-2185		2185-2186		2186-2187		2187-2188		2188-2189		2189-2190		2190-2191		2191-2192		2192-2193		2193-2194		2194-2195		2195-2196		2196-2197		2197-2198		2198-2199		2199-2200		2200-2201		2201-2202		2202-2203		2203-2204		2204-2205		2205-2206		2206-2207		2207-2208		2208-2209		2209-2210		2210-2211		2211-2212		2212-2213		2213-2214		2214-2215		2215-2216		2216-2217		2217-2218		2218-2219		2219-2220		2220-2221		2221-2222		2222-2223		2223-2224	
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Citizenship: U.S.A.
Post Office Address: Same

Date Signed: September 18th, 2000